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LAND CAPABILITY:
A HYDROLOGIC RESPONSE UNIT IN AGRICULTURAL WATERSHEDS

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CONTENTS

Page

Hydrologic soil groupings 2

Land-capability groupings 5

Conclusions 10

Literature cited 11

LAND CAPABILITY: A HYDROLOGIC RESPONSE UNIT IN AGRICULTURAL WATERSHEDS

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Soil surveys are developed to obtain and organize knowledge about observed soil properties so that the soil response to a proposed use may be predicted. Soil survey maps and reports, therefore, must include all important basic soil characteristics. However, only a limited number of these characteristics may be pertinent for a particular use. Characteristics that are not pertinent to the interpretation may vary widely within the soil groups which, according to the grouping criteria, are relatively similar. One such grouping will rarely suffice for other than its intended use.

For hydrologic considerations, soils are grouped by the characteristics that affect their response to hydrologic events. It is seldom prudent and often impossible to carry out research on each different soil within a complex watershed. Thus, the most practical groupings are those based on readily discernible or previously known properties that most reflect the soil's ability to absorb, store, and transmit water. These may include porosity, texture, depth, kind and arrangement of horizons, permeability, and conductivity.

Of primary concern are the characteristics of the soil's surface layer, the horizon of major hydrologic activity. In this surface layer rapid and early abstraction of rainfall occurs by infiltration, concentrated root activity removes water and provides infiltration opportunity for subsequent rainfall, and rapid lateral subsurface flow may occur. The capacity of the topsoil to retain storm rainfall has been described as the *first modifier of the land phases of the hydrologic cycle (6).*[2] This critical surface layer is also the one most affected by man's agricultural practices for food and fiber production or by land-use treatments that are applied for soil and water control.

The most serviceable hydrologic grouping of agricultural soils is one which includes (1) the hydrologic capacity of different soils, (2) their relative position on the landscape with respect to overland and subsurface flows, and (3) their adaptability to various land uses and treatments.

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[2] Underscored numbers in parentheses refer to Literature Cited, page 12.

The nature of soils classification depends primarily upon two factors: the use for which the classification is intended, and the kind and amount of soils data available. The use includes both usage and intended use. For example, usage includes field operations in the planning of land treatment measures, computations for design of water control structures, and research on mathematical simulation of watershed processes. Intended use, in turn, determines the kind of data needed. Thus, classifications that utilize broad categories, such as Great Soil Groups (16), may be used in river basin planning, whereas detailed soil surveys may be required in the design of farm ponds.

For most purposes, hydrologic soil classes should be defined on narrow ranges of infiltration rates and moisture capacities. This has proved virtually impossible for two reasons. First, data obtained from infiltrometers for the infiltration rate of many soils are not generally available. Where data are available, they cannot be applied to soils in different areas because the data were obtained by many procedures and with many kinds of equipment. Secondly, the determination must be made as to what infiltration parameter(s), what moisture capacity value(s), or whether both should be used for defining categories in the classification system. The determination then provides a basis for discussion of the various classifications. Data on infiltration rates are so variable, even within a soil mapping unit, that soils that are grouped on less variable criteria and more or less permanent features are emphasized.

Musgrave (12) placed thousands of U.S. soil series into four groups based upon the soil's *final constant or minimum rate of infiltration,* defined as the rate of intake after prolonged wetting. Infiltration analyses of runoff hydrographs from plots and small watersheds were supplemented by infiltrometer data in placing soils in the array.

The Soil Conservation Service of the U.S. Department of Agriculture subsequently placed over 6,000 soil series into Musgrave's grouping and adopted the groups as the basis for watershed planning. The groupings are used to derive *curve numbers* for soil-cover complexes in the rainfall-runoff relationship used in estimating maximum annual floods from agricultural watersheds (15). This classification system is appropriate for this purpose. First, the minimum infiltration rates by which the soil groups are classified would also be used to estimate runoff from major events, such as maximum annual floods, when it is reasonable to assume that the precipitation was of long duration and that the soils were fully wet. Secondly, field operations on a national scale, such as that of SCS, require the use of soil parameters that are universally applicable and for which values are either: (1) currently available; (2) easily obtainable by simple and rapid techniques; or (3) can be estimated from such known soil properties as soil texture, depth, and drainage.

TABLE 1.--Hydrologic soil groups used by the Soil Conservation Service

Hydrologic soil group	Soils included[1]	Final constant infiltration rate,(fc),in./hr.
A	(Low runoff potential) Soils having high infiltration rates even when thoroughly wetted, consisting chiefly of sands or gravel that are deep and well to excessively drained. These soils have a high rate of water transmission.	0.30 - 0.45
B	Soils having moderate infiltration rates when thoroughly wetted, chiefly moderately deep to deep, moderately well to well drained, with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.	0.15 - 0.30
C	Soils having slow infiltration rates when thoroughly wetted, chiefly with a layer that impedes the downward movement of water or of moderately fine to fine texture and a slow infiltration rate. These soils have a slow rate of water transmission. (high runoff potential)	0.05 - 0.15
D	Soils having very slow infiltration rates when thoroughly wetted, chiefly clay soils with a high swelling potential; soils with a high permanent water table; soils with a clay pan or clay layer at or near the surface; and shallow soils over nearly impervious materials. These soils have a very slow rate of water transmission.	0 to 0.05

[1] Soils are classed in the next lowest category when a high percentage of stones is present.

Texture of surface soil is the basis for another hydrologic grouping and is presented in the American Society of Civil Engineers *Hydrology Handbook* (1) as follows:

Infiltration rates for bare soils
at the end of 1 hour

Soil groups	Infiltration rate in./hr.
High	0.50 to 1.00
Intermediate	0.10 to 0.50
Low	0.01 to 0.10

The relationships between soil texture and porosity, water-holding capacity, and permeability are commonly observed. However, when surface texture is used as the sole criterion for a hydrologic classification of soil, other soil properties that can dominate the infiltration and water storage processes are ignored. These are namely, structure, mineralogy, drainage characteristics, and depth.

Catenas (11) and soil associations (17, 18) have been used as units for hydrologically classifying soils. Miller and Cary (10), for example, hydrologically classified 210 soil associations in the Susquehanna River basin by deriving weighted Soil Conservation Service curve numbers for the associations and by assigning A, B, C, or D categories to them. Associations are groups of individual soils that occur in repetitious patterns on the landscape and they differ from catenas in that catenas are toposequences of soils that differ in drainage characteristics.

Instead of using a weighted hydrologic parameter for grouping watershed soils, England and Onstad (3) and England and Holtan (2) grouped soils by their upper layer porosity and their position on the landscape. Hydrologic response units in the watersheds studied varied from deep, upland soils with high-storage capacity through shallow, eroded hillsides to very deep, alluvial-colluvial zones. A narrow range of surface soil porosity was found among the soils of a particular zone, but porosity varied widely among the zones. In other types of watersheds additional units would be required to represent the soils of terraces, escarpments, and other topographic regimes.

There are many advantages for grouping soils topographically by their surface soil porosity. Elevation sequences of soil groups are compatible with and, in fact, are responsible for variations in the hydraulics of surface and subsurface flows. For example, runoff generated by excess precipitation on upper zones almost invariably cascades over lower zones to combine with runoff generated there or to be absorbed. Computational routing of flows is thus simplified by a conceptual model that distributes the generated runoff into definable response units within the watershed and routes flow in a downhill sequence across or through subjacent zones. This model, then, forms the basic framework for consideration of the hydrologic performance of the entire fluvial system, regardless of the size of the area.

A second advantage of topographic grouping of soils is that the distribution of the soil groups defined as hydrologic response units is normally concomitant with the distribution of the various land uses or of the native vegetation within the watersheds. Thus, the roles of soils and land use can be considered simultaneously in a framework that is rationally consistent with the hydrologic performance of the landscape.

LAND-CAPABILITY GROUPINGS

The Soil Conservation Service long ago recognized the need for an interpretive soil grouping that would facilitate the use of soil survey information for farm planning. The Service now provides soil maps of individual farms and watersheds, interpreted into land-capability groupings, as a basis for conservation planning.

Land-capability groups are based indirectly on soil-landform characteristics but are based directly on the response of the groups to management required to keep them productive and to protect them from erosion and other hazards (9). Soil characteristics directly or indirectly considered in placing soils into land-capability groups, include depth and texture of topsoil, land slope, drainage (a function of the soil's internal permeability and topographic position), rockiness, salinity, and the productivity of the soil for plant growth. By considering these characteristics, farm planning specialists can prepare alternate plans for cropping, fertilizer application, irrigation, erosion control, and other management practices.

Because of the soil-landform characteristics on which they are indirectly based, land-capability groups appear to be suited for additional use as hydrologic response units. Topsoil features significant to infiltration, slope and topographic position, plus suitability to various land uses are held in common between units of the two types of groupings and appear to render them compatible. This premise was tested on the 3.01-square-mile Ralston Creek Watershed in Iowa. This particular watershed was selected because it is one of the oldest and best known experimental watersheds in the United States and has an available hydrologic record exceeding 45 years. The watershed is described in a bulletin published by the Iowa Highway Research Board (8) and includes a topographic map and an aerial photomosaic of soils prepared by the Soil Conservation Service in 1957. According to the bulletin, soils on Ralston Creek are typical of much of eastern and central Iowa and are comprised predominantly of Fayette silt loam (78 percent of the watershed). Downs silt loam, the Chaseburg-Nodaway complex, and undifferentiated alluvial soils occupy most of the remaining area. These soils, derived from loess, occur on slopes of up to 25 percent, and have friable, silty topsoils ranging in thickness from 0 to over 18 inches. Severe sheet and gully erosion has occurred on the steeper slopes. In addition to a description of the watershed soils, the bulletin presents land-capability classification for each soil mapping unit. Of the eight recognized classes, six (I, II, III, IV, VI and VII) are present on Ralston Creek Watershed. Susceptibility to erosion by water is the primary basis for grouping these soils into capability classes; however, excess water hazards from high water tables and flooding are present in much of the alluvial bottom land.

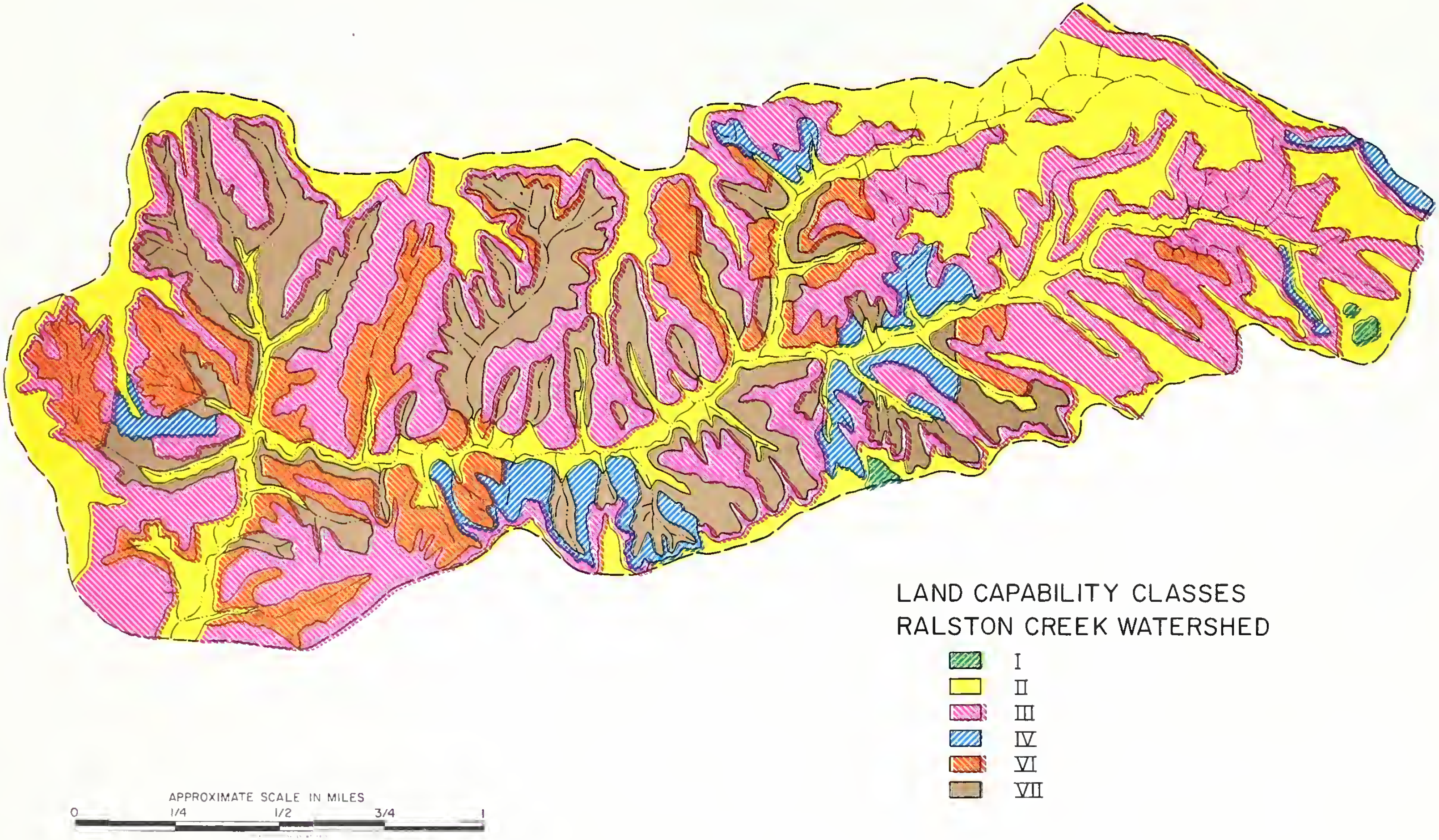
The distribution of land-capability classes is illustrated by the map in figure 1 which shows each mapped soil unit in the standard colors adopted by the Soil Conservation Service for this purpose.

A band of nearly level but poorly drained Class II soil follows the narrow flood plain throughout its extent. Another band of gently sloping Class II soil occurs around the perimeter of the watershed. Between these two zones the remaining classes, which tend to occur in more or less concentric bands roughly on contour around the hillsides, form a repetitive down-elevation sequence: II, III, IV, VI, VII, II. This is not always true within the watershed; in some cases, water en route downslope from the uplands would flow directly onto the alluvium, Class II. The complete sequence occurs frequently enough, however, to use it as a generality in developing a conceptual model of this area.

The classes present and their elevation sequence on other watersheds may be quite different from that of Ralston Creek because of differences in modes of soil and landscape formation. Ruhe (14), for example, found in some locations in Iowa that erosion of superposed layers of loess, varying in age, has exposed several surfaces which occur in an elevation sequence and on each of which there has developed a particular suite of soils.

Table 2 lists the soils of Ralston Creek Watershed as grouped by the Soil Conservation Service into land-capability classes. If soil associations had been used as the basis for grouping, all of these soils would be classed into one group. A catena is present in this watershed; the Fayette, Stronghurst, and Traer series form a sequence of well, moderately well, and poorly to very poorly drained soils. Major differences in hydrologic capacity, topographic position, and land-capability are found within the Fayette series as a result of erosion. Grouping by series, associations, or catenas would mask the important differences in depth of topsoil between the relatively uneroded Fayette soils of the uplands and the moderately to severely eroded Fayette soils on the slopes.

To illustrate the differences in the hydrologic capacities of the land-capability classes, estimates were made of three important soil moisture characteristics which have been successfully used as parameters in mathematical models of watershed performance (5). Data used in obtaining estimates of these parameters were taken from a compilation of soil moisture-tension measurements made on soil samples from watersheds over the United States (7) and which compare with data elsewhere (4). The parameters are: S, total storage capacity, determined as total porosity minus 15-bar moisture retention; G, *gravitational or free* water storage capacity, the porosity between



LAND CAPABILITY CLASSES
RALSTON CREEK WATERSHED

TABLE 2.-- Land-capability classes and soil characteristics, Ralston Creek Watershed, Iowa

Land capability class	Soil and texture	Slope range	Approx. area	Degree of erosion	Topsoil thickness
		Percent	Acres		Inches
I	Atterberry silt loam	0-1	4.0	None	16
	Stronghurst silt loam	0-1	2.0	None	10
		Total	6.0		
IIe	Stronghurst silt loam	2-4	1.0	None	10
	Atterberry silt loam	2-4	24.0	Slight	14
	Downs silt loam	2-4	133.0	Slight sheet	10
	Fayette silt loam	2-4	198.0	Slight sheet	9
		Total	355.0		
IIw	Dark alluvial soils undifferentiated	2-4	26.0	None	18+
	Chaseburg-Nodaway complex	2-4	182.0	Moderate gully	18+
	Garwin silty clay loam	0-1	10.0	None	18
	Traer silt loam	0-1	1.0	None	6
		Total	219.0		
IIIe	Downs silt loam	5-8	7.0	Slight sheet	8
	Downs silt loam	5-8	23.0	Moderate sheet	5
	Fayette silt loam	5-8	47.0	Slight sheet	8
	Fayette silt loam	5-8	179.0	Moderate sheet	5
	Fayette silt loam	9-13	8.0	Slight sheet	7
	Fayette silt loam	9-13	333.0	Moderate sheet	5
		Total	597.0		
IVe	Fayette silt loam	9-13	62.0	Severe, sheet and gully	2
	Fayette silt loam	14-17	66.0	Moderate	4
		Total	128.0		
VIe	Fayette silt loam	14-17	96.0	Severe, sheet and gully	2
	Fayette silt loam	18-24	31.0	Slight sheet	5
	Fayette silt loam	18-24	107.0	Moderate sheet	3
		Total	234.0		
VIIe	Fayette silt loam	18-24	221.0	Severe, sheet and gully	0
	Fayette silt loam	25+	57.0	Slight sheet	4
	Fayette silt loam	25+	65.0	Moderate	2
	Fayette silt loam	25+	10.0	Severe, sheet and gully	0
	Lindley loam	9-13	3.0	Severe, sheet and gully	0
	Lindley loam	18-24	6.0	Severe, sheet and gully	0
		Total	362.0		

total porosity and that filled with water at 0.33 bar; and AWC, *plant-available* water capacity, the remainder of (S-G). These three values were determined on thousands of soil samples of various textures. Mean values by texture classes are presented in table 3.

TABLE 3.--Hydrologic capacities of texture classes

Texture class	Storage capacity S	Large pores G	Plant-available porosity AWC
	(percent)	(percent)	(percent)
Coarse sand	24.4	17.7	6.7
Coarse sandy loam	24.5	15.8	8.7
Sand	32.3	19.0	13.3
Loamy sand	37.0	26.9	10.1
Loamy fine sand	32.6	27.2	5.4
Sandy loam	30.9	18.6	12.3
Fine sandy loam	36.6	23.5	13.1
Very fine sandy loam	32.7	21.0	11.7
Loam	30.0	14.4	15.6
Silt loam	31.3	11.4	19.9
Sandy clay loam	25.3	13.4	11.9
Clay loam	25.7	13.0	12.7
Silty clay loam	23.3	8.4	14.9
Sandy clay	19.4	11.6	7.8
Silty clay	21.4	9.1	12.3
Clay	18.8	7.3	11.5

From table 3, values of S, G and AWC for the textures represented on Ralston Creek watershed were multiplied by average topsoil depths for the appropriate capability classes. The results are presented in table 4, where the extreme differences in hydrologic capacities among land-capability classes can readily be seen. When these results are compared with the average weighted values (at bottom of the table) that would have been obtained by weighted averaging over the entire watershed, the contrast should emphasize the importance of determining the spatial distribution of runoff-contributing areas within the watershed. The areas with relatively low capacity for absorbing rainfall (classes IV, VI, and VII) will shed almost all storm precipitation; these areas are also the steepest, so overland and subsurface flow rates will be maximum. Flows from this zone traverse the class II bottom land, which may, because of its depth, absorb much of the runoff from upper zones. If wet, however, the bottom land would also become a direct contributor to the storm hydrograph from the watershed. The class I, II and III lands at the higher elevations would be expected to contribute to watershed runoff only during extreme events when rates or volumes of rainfall exceeded the capacities of these classes.

TABLE 4.--Estimated hydrologic parameters for land-capability classes on Ralston Creek Watershed, Iowa

Land capability class	Approx. area	Weighted average topsoil thickness	Average slope range	Hydrologic parameters: Storage capacity, S	Hydrologic parameters: Large pores, G	Hydrologic parameters: Plant-available porosity AWC
	(acres)	(inches)	(percent)	(inches)	(inches)	(inches)
I	6	14	0-1	4.5	1.8	2.7
IIe	356	10	2-4	3.2	1.2	2.0
IIw	219	[1] 18	0-4	5.8	2.3	3.3
IIIe	597	5	5-13	1.6	0.6	1.0
IVe	128	3	9-17	1.0	0.4	0.6
VIe	234	3	14-24	1.0	0.4	0.6
VIIe	362	1	9-25+	0.3	0.1	0.2
Total:	1902					
Watershed weighted averages:		6	10	2.0	0.8	1.2

[1] Estimated as average water table depth.

The performance of the entire watershed depends to a great extent upon the spatial distribution of hydrologic response units. If units of low capacity are located close to the stream channel, runoff would be initiated early and the total runoff probably would be greater than if the low-capacity, high-runoff-contributing areas were located high above the stream and above the more pervious areas that are capable of absorbing more water.

Stratifying the watershed into land-capability classes also offers an opportunity to assess the role of land use on watershed hydrology. Soil classes suitable for cultivation (I, II, and III) are the areas of greatest hydrologic capacity. Soils in the higher classes (IV, VI and VII) are suited for grass or forests -- the areas where topsoils are thinnest and moisture capacities lowest. For estimates of watershed performance, land-capability groupings afford the best estimate not only for land use and spatial distribution, but, because of their relation to hydrologic capacity, they provide units for predicting the hydrologic performance of watersheds.

CONCLUSIONS

Understanding the hydrology of agricultural watersheds requires a knowledge of the spatial distribution of runoff-contributing and runoff-absorbing areas and their relation to each other. Soil surveys, interpreted into land-capability groupings, can provide a tool for assessing spatial distribution, and thus appear to offer promise as a serviceable and, fortunately, already established hydrologic soil grouping. Land-capability classes are based on the same soil-landform criteria as those used in hydrologic soil groupings: *surface moisture capacities and position on the landscape*. In addition, land-capability classes are intuitively unique in land use and provide a basis for futuristic estimates of land use as well as hydrologic performance. This concept is exploratory and is offered here as an inducement for discussion and, hopefully, further testing.

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